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User Manual for the Generic Directivity Index (GenDI) Program (Version 1.0.5)

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PREFACE

This document was prepared by Andrew J. Hull while assigned to the Office of Naval Intelligence (ONI) in Washington, DC, by NUWC Division Newport's Field Team Operations Office (Code 01T). Funding for the task was provided under ONI Project No. 000151V0679Q, "S&T Intelligence Assessment in Acoustic Sensors," project manager John Zilius (ONI-241).

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13. ABSTRACT (Maximum 200 words)

This document is the user manual for the Generic Directivity Index (GenDI) Program. Designed to calculate the directivity index of 10 predefined geometry shapes for linear, planar, and volumetric arrays, the program is also able to read a user-prescribed sensor geometry file for irregularly shaped or weighted arrays. Included in the manual are a description of the basic theory behind GenDI, the program commands and flowcharts, and validation procedures.

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USER MANUAL FOR THE GENERIC DIRECTIVITY INDEX (GenDI) PROGRAM (VERSION 1.0.5)*

1. INTRODUCTION

GenDI is a MATLAB program that calculates the directivity index of an array of sensors. The directivity index is defined as a decibel measure of the improvement in the signal-to-noise ratio (SNR) that a beamformed array provides in an ideal isotropic noise field with a perfectly correlated signal relative to an omnidirectional element in the free field.[1] Mathematically, this index is expressed as

$$DI = 10\log_{10} DF = 10\log_{10} \frac{SNR_{array}}{SNR_{element}} , \tag{1}$$

where DF denotes the directivity factor. The directivity factor is given as

$$DF = \frac{4\pi}{\int_0^{2\pi}\int_0^{\pi} \left\{ \frac{\left|A(\theta - \theta_s, \phi - \phi_s)\right|^2}{\max\left[\left|A(\theta - \theta_s, \phi - \phi_s)\right|^2\right]} \right\} \sin\phi \; d\phi \; d\theta} , \tag{2}$$

where $A(\theta - \theta_s, \phi - \phi_s)$ is the beam pattern response of the array, θ is the azimuthal angle, ϕ is the polar angle (or sometimes the declination or depression angle), θ_s is the steer angle in the azimuthal direction, and ϕ_s is the steer angle in the polar direction. The beam pattern is computed using

$$A(\theta - \theta_s, \phi - \phi_s) =$$

$$\sum_{m=1}^{M} w_m \exp[+\mathrm{i}x_m(k_x - k_{xs})]\exp[+\mathrm{i}y_m(k_y - k_{ys})]\exp[+\mathrm{i}z_m(k_z - k_{zs})] , \tag{3}$$

*The version number for the GenDI program consists of three numbers separated by dots. The current program is version 1.0.5 — the first number shows the primary program version, the second represents its revision, and the third is the version of MATLAB that is compatible with GenDI. Although GenDI was designed using MATLAB 5.3, it is likely that it will run successfully with subsequent versions.

where M is the total number of sensors, w_m is the weight (or shade) of the mth sensor, i is the square root of -1, x_m is the x-position of the mth sensor, k_x is the wavenumber of the incoming wave with respect to the x-axis, k_{xs} is the steer orientation in the x-direction, y_m is the y-position of the mth sensor, k_y is the wavenumber of the incoming wave with respect to the y-axis, k_{ys} is the steer orientation in the y-direction, z_m is the z-position of the mth sensor, k_z is the wavenumber of the incoming wave with respect to the z-axis, and k_{zs} is the steer orientation in the z-direction. The wavenumbers are expressed as

$$k_x = \frac{\omega}{c} \cos\theta \sin\phi \ , \tag{4}$$

$$k_y = \frac{\omega}{c} \sin\theta \sin\phi \ , \tag{5}$$

$$k_z = \frac{\omega}{c} \cos\phi \ , \tag{6}$$

where ω is the frequency (rad/s) and c is the wavespeed (m/s). The steer orientation of the array is given by

$$k_{xs} = \frac{\omega}{c} \cos\theta_o \sin\phi_o \ , \tag{7}$$

$$k_{ys} = \frac{\omega}{c} \sin\theta_o \sin\phi_o \ , \tag{8}$$

$$k_{zs} = \frac{\omega}{c} \cos\phi_o \ . \tag{9}$$

The preceding nine equations form the basis for all the computations in the GenDI program. Their calculation has been based on the orientation of the Cartesian coordinate system to the spherical coordinate system shown in figure 1.

Although numerous papers have been written on the subject of directivity index calculations,[1-5] discussion or expansion upon such theoretical works is not presented here. The intent of this document is to provide the reader with a basic manual for using the GenDI program.

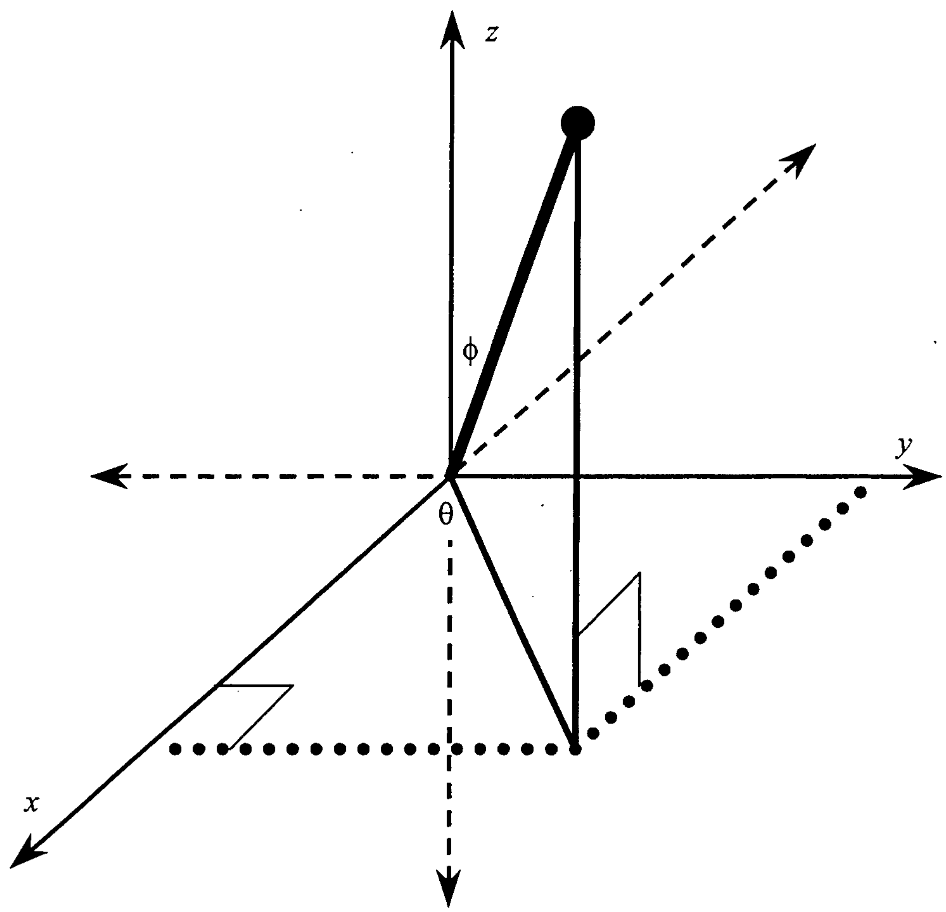

Figure 1. Relationship Between Cartesian and Spherical Coordinate Systems

2. PREPROCESSING

The GenDI program has 10 predefined array geometry shapes that can be interactively manipulated to address the various dimensions and numbers of sensors. Additionally, the program is able to read a user-prescribed sensor geometry file for irregularly shaped or weighted arrays. In all preprocessing modules, the array is graphically displayed to the screen so that the user can view the geometry that is currently defined. The individual preprocessing capabilities are described below.

HORIZONTAL SINGLE-LINE ARRAY

This routine creates a single-line array (typically a towed array) on the positive y-axis, as shown in figure 2. Broadside to this array is an azimuthal steer angle of 0°. The following commands are available:

Channel Spacing (m) – Changes the channel spacing of the array (units are entered in meters). Changing this value also alters the array length.

Number of Channels – Changes the number of channels in the array.

Array Length (m) – Changes the length of the array (units are entered in meters). Changing this value also alters the channel spacing.

Aperture Shading – Sets the aperture shading of the array. Shading is available using uniform (boxcar), hamming, hanning, or triangular weights.

Input Integration Parameters – Directs the program to the next window, which inputs the integration parameters.

Return to Start – Directs the program back to the initial window without running an analysis.

Exit Program – Exits the GenDI program and closes associated windows.

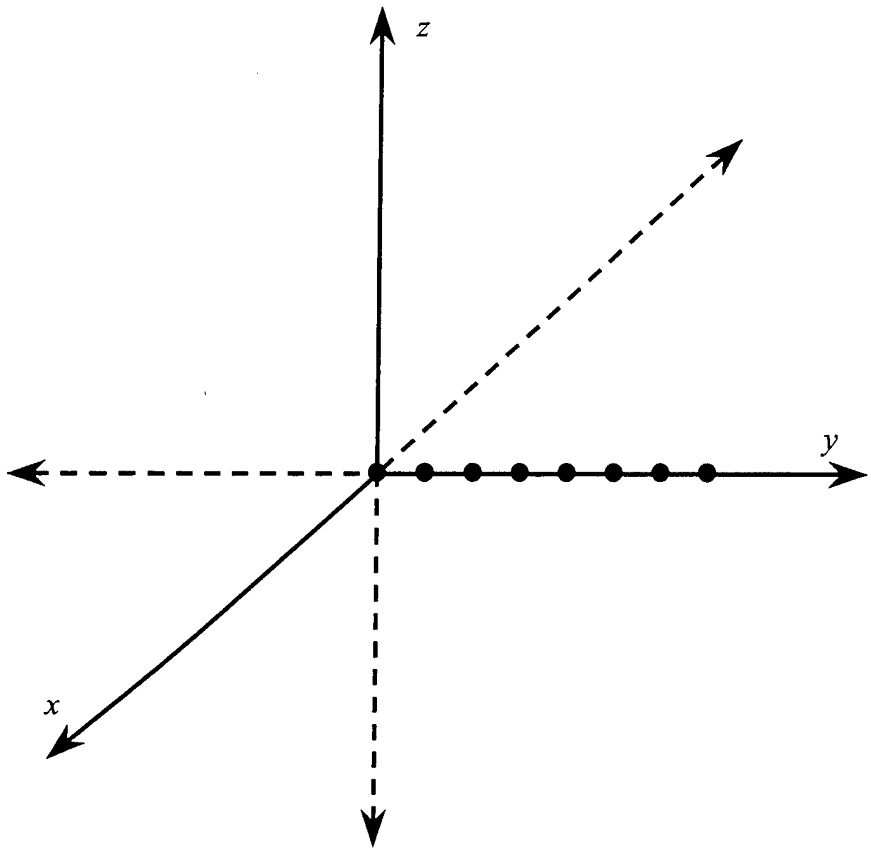

Figure 2. Horizontal Single-Line Array

VERTICAL SINGLE-LINE ARRAY

This routine creates a single-line array (typically a bottom-mounted (moored) array) on the positive z-axis, as shown in figure 3. Broadside to this array is a polar steer angle of 90°. The following commands are available:

Channel Spacing (m) – Changes the channel spacing of the array (units are entered in meters). Changing this value also alters the array length.

Number of Channels – Changes the number of channels in the array.

Array Length (m) – Changes the length of the array (units are entered in meters). Changing this value also alters the channel spacing.

Aperture Shading – Sets the aperture shading of the array. Shading is available using uniform (boxcar), hamming, hanning, or triangular weights.

Input Integration Parameters – Directs the program to the next window, which inputs the integration parameters.

Return to Start – Directs the program back to the initial window without running an analysis.

Exit Program – Exits the GenDI program and closes associated windows.

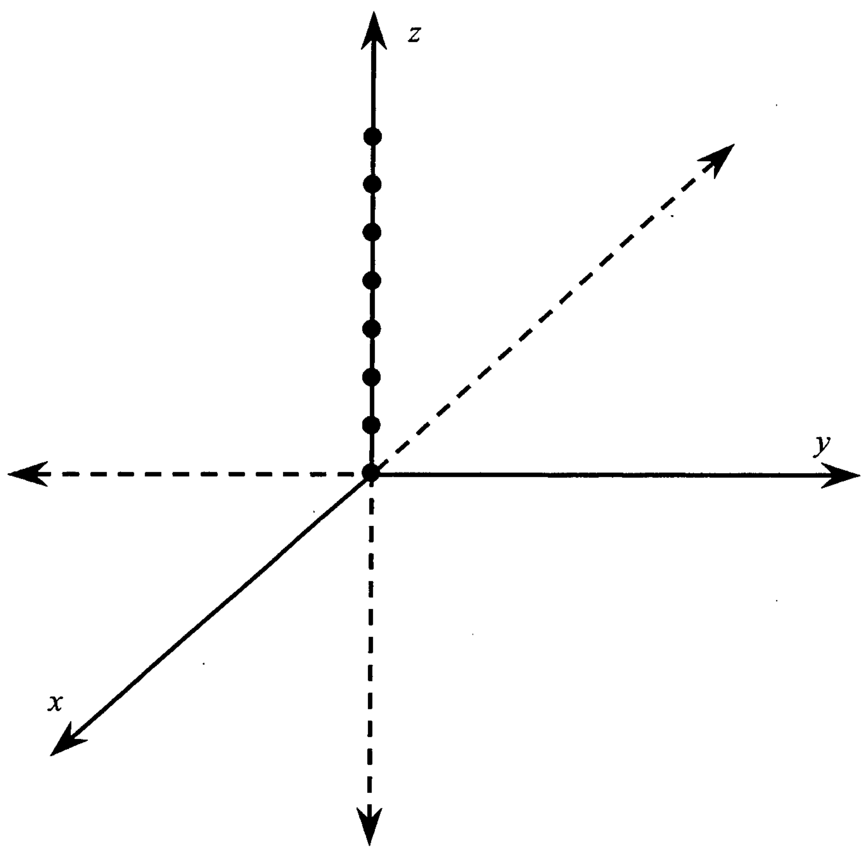

Figure 3. Vertical Single-Line Array

MULTILINE ARRAY

This routine creates a multiline array that resides in the *xy*-plane. The array lines are oriented along the positive *y*-axis and the middle of the line system is centered at $x = 0$, which is typical for a multiline towed array system (see figure 4). Broadside to this array system is an azimuthal steer angle of 0° and a polar steer angle of 90°. The following commands are available:

Number of Chan per Line – Changes the number of channels on each individual line (i.e., the number of sensors in the *y*-direction).

Channel Spacing (m) – Changes the channel spacing of the array in the *y*-direction (units are entered in meters). Changing this value also alters the array length.

Array Length (m) – Changes the length of the array in the *y*-direction (units are entered in meters). Changing this value also alters the channel spacing.

Inter-Array Shading – Sets the aperture shading of the array along the *y*-axis. Shading is available using uniform (boxcar), hamming, hanning, or triangular weights.

Number of Arrays – Changes the number of array lines (i.e., the number of sensors in the *x*-direction).

Line Spacing (m) – Changes the spacing between each array line (units are entered in meters).

Intra-Array Shading – Sets the aperture shading across the array (*x*-axis direction). Shading is available using uniform (boxcar), hamming, hanning, or triangular weights.

Input Integration Parameters – Directs the program to the next window, which inputs the integration parameters.

Return to Start – Directs the program back to the initial window without running an analysis.

Exit Program – Exits the GenDI program and closes associated windows.

Reset Graphics – Resets the graphics window. The MATLAB graphics window sometimes becomes "contaminated" and draws in areas that it should not. This command resets the entire window to the proper size.

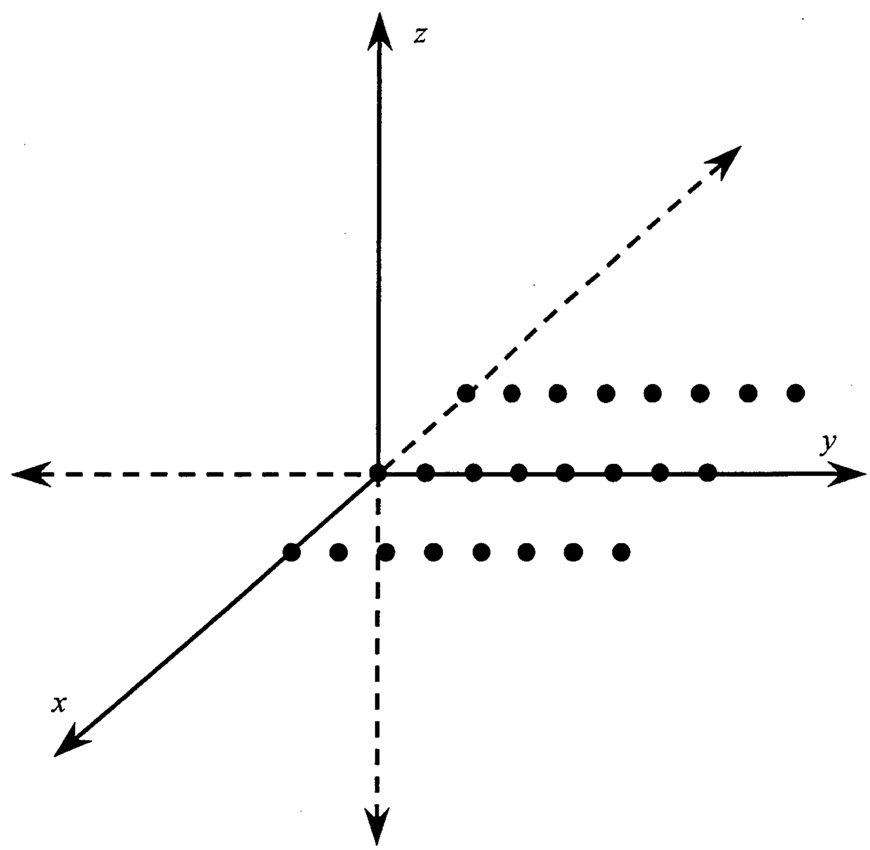

Figure 4. Multiline Array

PLANAR TWO-DIMENSIONAL ARRAY

This routine creates a planar two-dimensional array (typically a submarine-mounted flank array) in the positive *yz*-quadrant, as shown in figure 5. Broadside to this array is an azimuthal steer angle of 0° and a polar steer angle of 90°. The following commands are available:

Number of Columns – Changes the number of columns in the array.

Column Spacing (m) – Changes the column-to-column spacing of the array (units are entered in meters). Changing this value also alters the array width.

Array Width (m) – Changes the width of the array (units are entered in meters). Changing this value also alters the column spacing.

Column Shading – Sets the aperture shading along the length of the column. Shading is available using uniform (boxcar), hamming, hanning, or triangular weights.

Number of Rows – Changes the number of rows in the array.

Row Spacing (m) – Changes the row-to-row spacing of the array (units are entered in meters). Changing this value also alters the array height.

Array Height (m) – Changes the height of the array (units are entered in meters). Changing this value also alters the row spacing.

Row Shading – Sets the aperture shading along the length of the row. Shading is available using uniform (boxcar), hamming, hanning, or triangular weights.

Input Integration Parameters – Directs the program to the next window, which inputs the integration parameters.

Return to Start – Directs the program back to the initial window without running an analysis.

Exit Program – Exits the GenDI program and closes associated windows.

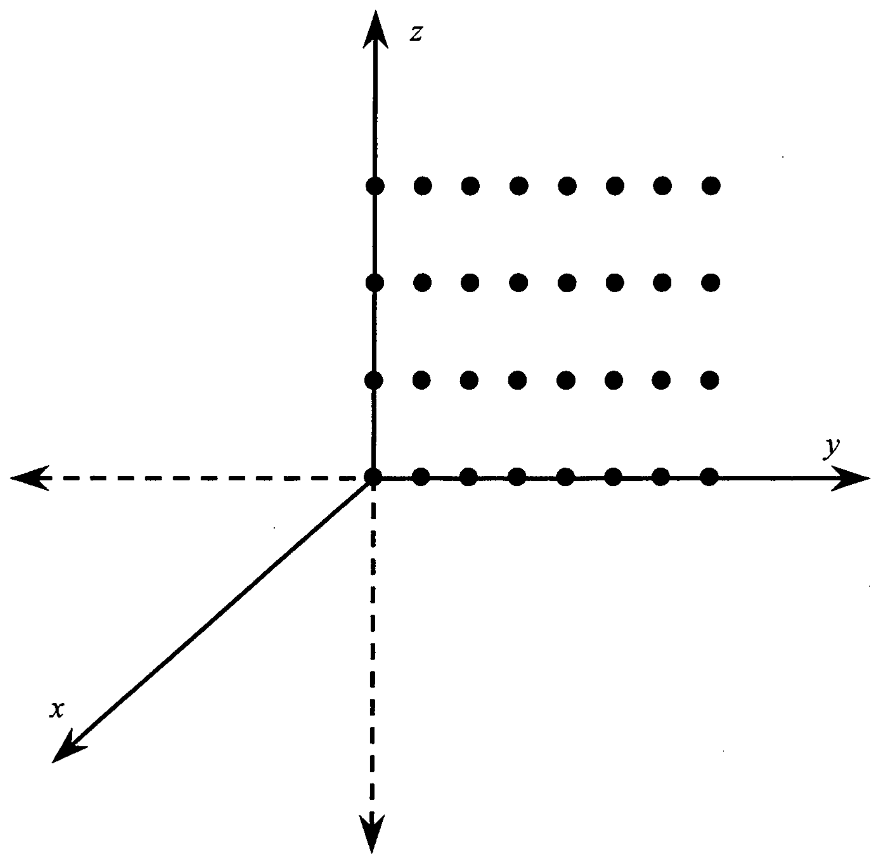

Figure 5. Planar Two-Dimensional Array

PARTIAL-CYLINDER HORIZONTAL ARRAY

This routine creates a partial-cylinder horizontal array (typically a conformal submarine-mounted flank array), as shown in figure 6. Broadside to this array is an azimuthal steer angle of 0° and a polar steer angle of 90°. The following commands are available:

Number of Columns – Changes the number of columns in the array.

Column Spacing (m) – Changes the column-to-column spacing of the array (units are entered in meters). Changing this value also alters the array width.

Array Width (m) – Changes the width of the array (units are entered in meters). Changing this value also alters the column spacing.

Column Shading – Sets the aperture shading along the length of the columns. Shading is available using uniform (boxcar), hamming, hanning, or triangular weights.

Number of Rows – Changes the number of rows in the array. Rows are equally spaced along the partial cylinder, starting at the top angle and ending at the bottom angle.

Cylinder Radius (m) – Changes the radius of the partial cylinder (units are entered in meters).

Top Angle (degrees) – Changes the top angle of the array, which is measured from the *xy*-plane, positive in the positive *z*-direction. The angle (input in degrees) must be greater than 0.

Bottom Angle (degrees) – Changes the bottom angle of the array. This angle is measured from the *xy*-plane, positive in the negative *z*-direction. The angle (input in degrees) must be greater than 0.

Row Shading – Sets the aperture shading along the length of the rows. Shading is available using uniform (boxcar), hamming, hanning, or triangular weights.

Input Integration Parameters – Directs the program to the next window, which inputs the integration parameters.

Return to Start – Directs the program back to the initial window without running an analysis.

Exit Program – Exits the GenDI program and closes associated windows.

Reset Graphics – Resets the graphics window. The MATLAB graphics window sometimes becomes "contaminated" and draws in areas that it should not. This command resets the entire window to the proper size.

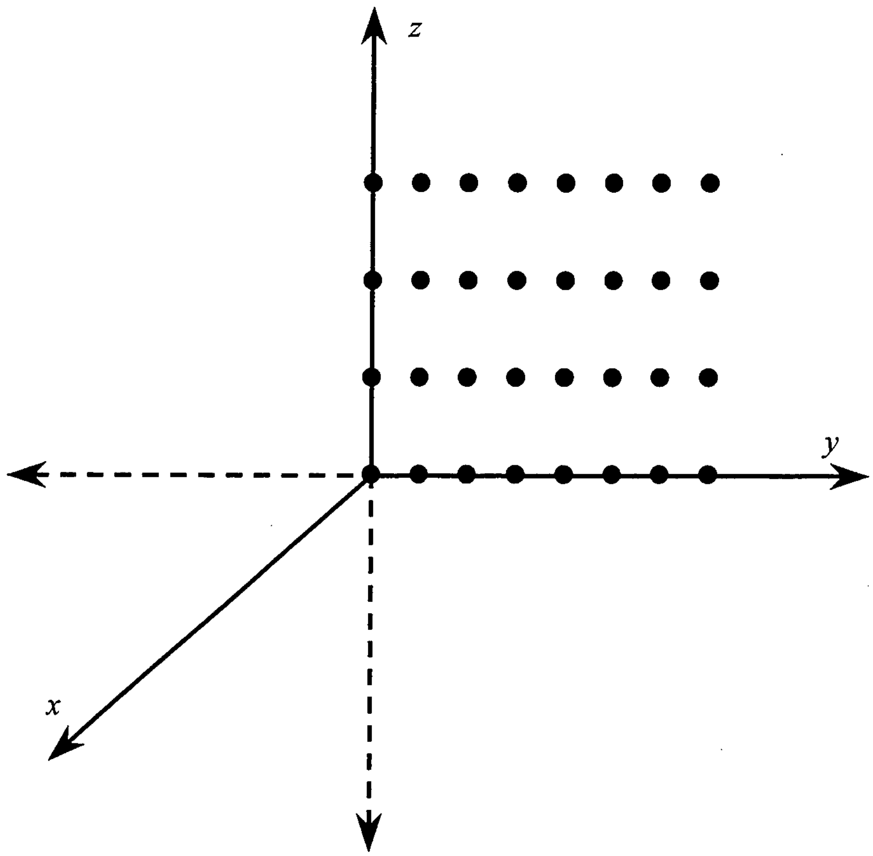

Figure 5. Planar Two-Dimensional Array

PARTIAL-CYLINDER HORIZONTAL ARRAY

This routine creates a partial-cylinder horizontal array (typically a conformal submarine-mounted flank array), as shown in figure 6. Broadside to this array is an azimuthal steer angle of 0° and a polar steer angle of 90°. The following commands are available:

Number of Columns – Changes the number of columns in the array.

Column Spacing (m) – Changes the column-to-column spacing of the array (units are entered in meters). Changing this value also alters the array width.

Array Width (m) – Changes the width of the array (units are entered in meters). Changing this value also alters the column spacing.

Column Shading – Sets the aperture shading along the length of the columns. Shading is available using uniform (boxcar), hamming, hanning, or triangular weights.

Number of Rows – Changes the number of rows in the array. Rows are equally spaced along the partial cylinder, starting at the top angle and ending at the bottom angle.

Cylinder Radius (m) – Changes the radius of the partial cylinder (units are entered in meters).

Top Angle (degrees) – Changes the top angle of the array, which is measured from the xy-plane, positive in the positive z-direction. The angle (input in degrees) must be greater than 0.

Bottom Angle (degrees) – Changes the bottom angle of the array. This angle is measured from the xy-plane, positive in the negative z-direction. The angle (input in degrees) must be greater than 0.

Row Shading – Sets the aperture shading along the length of the rows. Shading is available using uniform (boxcar), hamming, hanning, or triangular weights.

Input Integration Parameters – Directs the program to the next window, which inputs the integration parameters.

Return to Start – Directs the program back to the initial window without running an analysis.

Exit Program – Exits the GenDI program and closes associated windows.

Reset Graphics – Resets the graphics window. The MATLAB graphics window sometimes becomes "contaminated" and draws in areas that it should not. This command resets the entire window to the proper size.

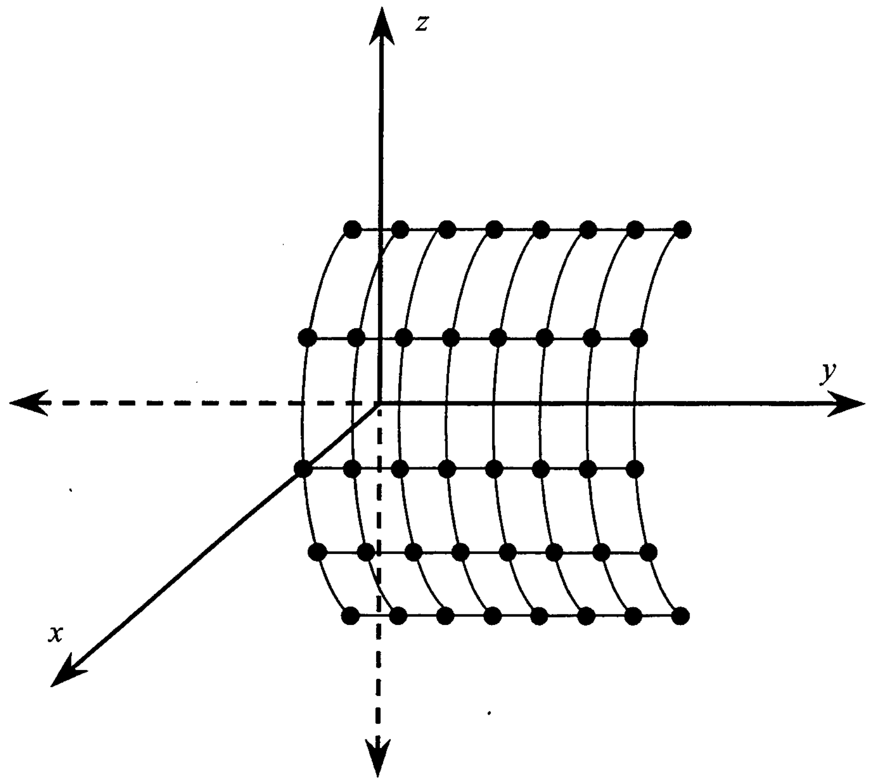

Figure 6. Partial-Cylinder Horizontal Array

FULL-CYLINDER VERTICAL ARRAY

This routine creates a full-cylinder vertical array (typically a cylindrical submarine bow array), as shown in figure 7. Broadside to this array is an azimuthal steer angle of 0° and a polar steer angle of 90°. The array is always oriented so that the leading column of sensors is located at $x = 0$ and $y = r$, where r is the radius of the cylinder. The following commands are available:

Number of Columns – Changes the number of columns in the array. Columns are equally spaced around the entire circumference of the array.

Column Spacing (degrees) – Changes the column-to-column spacing of the array (units are entered in degrees). Changing this value also alters the number of columns. Value is rounded to the nearest degree that is needed to populate the array with an integer number of columns.

Array Radius (m) – Changes the radius of the array (units are entered in meters).

Column Shading – Sets the aperture shading along the length of the columns. Shading is available using uniform (boxcar), hamming, hanning, or triangular weights.

Number of Rows – Changes the number of rows in the array.

Row Spacing (m) – Changes the row-to-row spacing of the array (units are entered in meters). Changing this value also alters the array height.

Array Height (m) – Changes the height of the array (units are entered in meters). Changing this value also alters the row spacing.

Row Shading – Sets the aperture shading along the length of the row. Shading is available using uniform (boxcar), hamming, hanning, or triangular weights. If hamming, hanning, or triangular shading is selected, the maximum weight value corresponds to the row located at $y = r$ (the front of the submarine).

Input Integration Parameters – Directs the program to the next window, which inputs the integration parameters.

Return to Start – Directs the program back to the initial window without running an analysis.

Exit Program – Exits the GenDI program and closes associated windows.

Reset Graphics – Resets the graphics window. The MATLAB graphics window sometimes becomes "contaminated" and draws in areas that it should not. This command resets the entire window to the proper size.

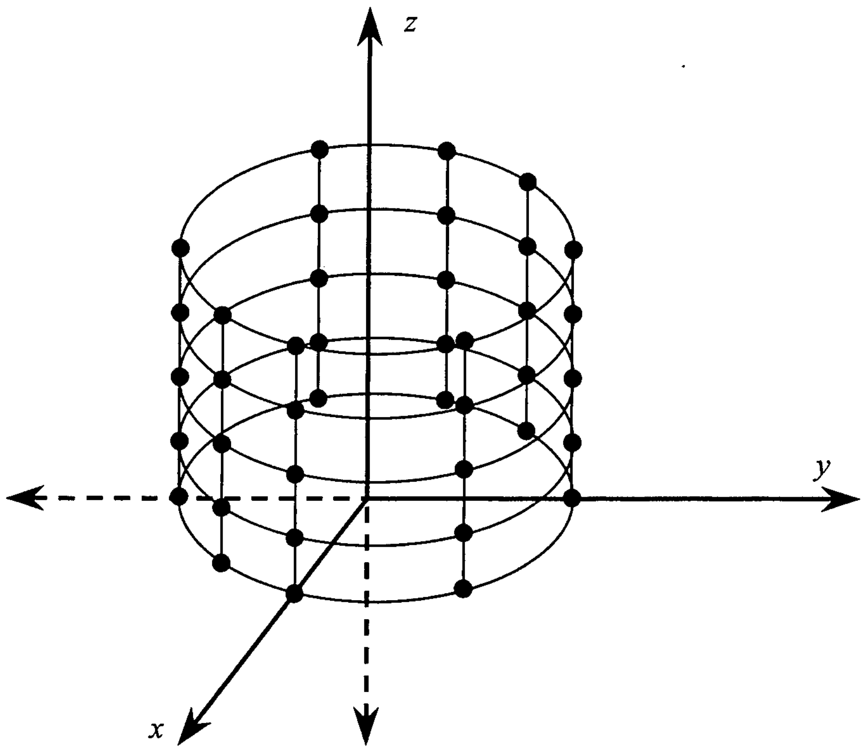

Figure 7. Full-Cylinder Vertical Array

PARTIAL-CYLINDER VERTICAL ARRAY

This routine creates a partial-cylinder vertical array (typically a submarine bow array), as shown in figure 8. Broadside to this array is an azimuthal steer angle of 0° and a polar steer angle of 90°. The array is symmetric with respect to the *y*-axis. The following commands are available:

Number of Columns – Changes the number of columns in the array. Columns are equally spaced around the entire circumference of the array.

Cylinder Radius (m) – Changes the radius of the array (units are entered in meters).

Total Angle (degrees) – Changes the total angle of the array (units are entered in degrees). The total angle of the array is seen in the portion of the cylinder that is populated with sensors.

Column Shading – Sets the aperture shading along the length of the columns. Shading is available using uniform (boxcar), hamming, hanning, or triangular weights.

Number of Rows – Changes the number of rows in the array.

Row Spacing (m) – Changes the row-to-row spacing of the array (units are entered in meters). Changing this value also alters the array height.

Array Height (m) – Changes the height of the array (units are entered in meters). Changing this value also alters the row spacing.

Row Shading – Sets the aperture shading along the length of the row. Shading is available using uniform (boxcar), hamming, hanning, or triangular weights. If hamming, hanning, or triangular shading is selected, the maximum weight value corresponds to the row with the maximum y value (the front of the submarine).

Input Integration Parameters – Directs the program to the next window, which inputs the integration parameters.

Return to Start – Directs the program back to the initial window without running an analysis.

Exit Program – Exits the GenDI program and closes associated windows.

Reset Graphics – Resets the graphics window. The MATLAB graphics window sometimes becomes "contaminated" and draws in areas that it should not. This command resets the entire window to the proper size.

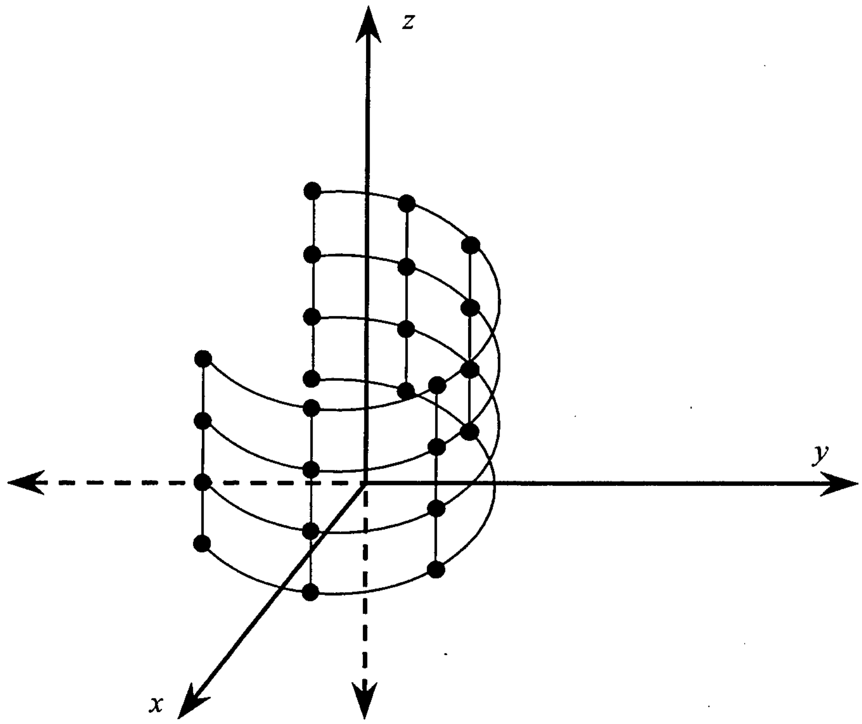

Figure 8. Partial-Cylinder Vertical Array

FULL-SPHERE ARRAY

This routine creates a full-sphere array (typically a submarine bow array), as shown in figure 9. The array is oriented so that one column of sensors is located at $y = r$. The following commands are available:

Number of Columns – Changes the number of columns in the array. Columns are equally spaced around the entire circumference of the array.

Array Radius (m) – Changes the radius of the array (units are entered in meters).

Column Shading – Sets the aperture shading along the length of the columns. Shading is available using uniform (boxcar), hamming, hanning, or triangular weights.

Number of Rows – Changes the number of rows in the array. The rows are equally spaced in the polar angular direction, starting at the spacing angle of the row (not 0°) and incrementing to 180° minus the spacing angle (not 180°). Broadside to this array is an azimuthal steer angle of 0° and a polar steer angle of 90°.

Row Shading – Sets the aperture shading along the length of the row. Shading is available using uniform (boxcar), hamming, hanning, or triangular weights. If hamming, hanning, or triangular shading is selected, the maximum weight value corresponds to the row located at $y = r$ (the front of the submarine).

Input Integration Parameters – Directs the program to the next window, which inputs the integration parameters.

Return to Start – Directs the program back to the initial window without running an analysis.

Exit Program – Exits the GenDI program and closes associated windows.

Reset Graphics – Resets the graphics window. The MATLAB graphics window sometimes becomes "contaminated" and draws in areas that it should not. This command resets the entire window to the proper size.

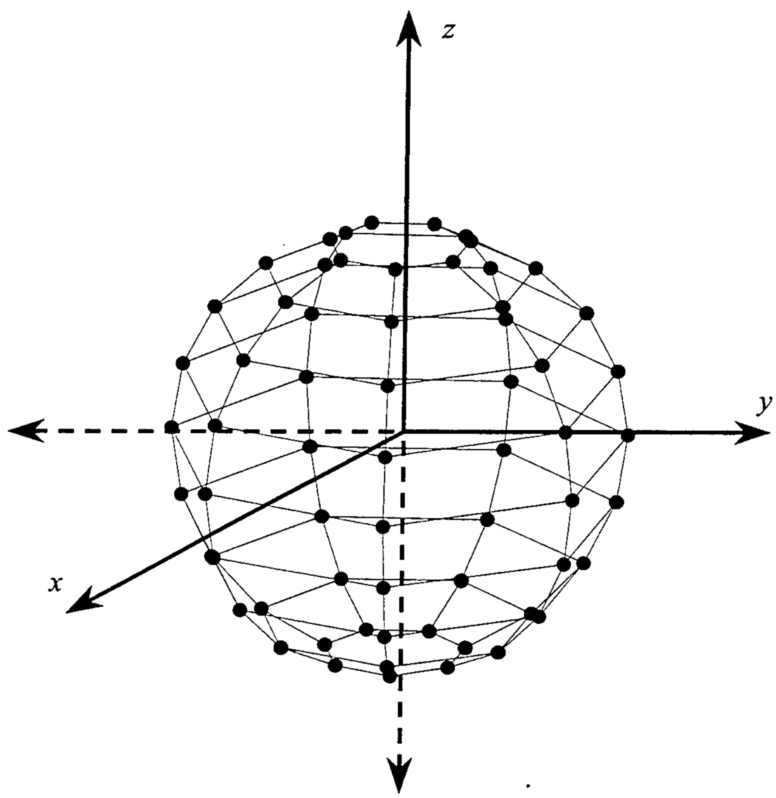

Figure 9. Full-Sphere Array

HALF-SPHERE ARRAY

This routine creates a half-sphere array (typically a submarine bow array), as shown in figure 10. Broadside to this array is an azimuthal steer angle of 0° and a polar steer angle of 90°. The following commands are available:

Number of Columns – Changes the number of columns in the array. Columns are equally spaced in the azimuthal angular direction, starting at $x = r$ and $y = 0$ and ending at $x = -r$ and $y = 0$.

Array Radius (m) – Changes the radius of the array (units are entered in meters).

Column Shading – Sets the aperture shading along the length of the columns. Shading is available using uniform (boxcar), hamming, hanning, or triangular weights.

Number of Rows – Changes the number of rows in the array. The rows are equally spaced in the polar angular direction, starting at the spacing angle of the row (not 0°) and incrementing to 180° minus the spacing angle (not 180°). Broadside to this array is an azimuthal steer angle of 0° and a polar steer angle of 90°.

Row Shading – Sets the aperture shading along the length of the row. Shading is available using uniform (boxcar), hamming, hanning, or triangular weights. If hamming, hanning, or triangular shading is selected, the maximum weight value corresponds to the row located at $y = r$ (the front of the submarine).

Input Integration Parameters – Directs the program to the next window, which inputs the integration parameters.

Return to Start – Directs the program back to the initial window without running an analysis.

Exit Program – Exits the GenDI program and closes associated windows.

Reset Graphics – Resets the graphics window. The MATLAB graphics window sometimes becomes "contaminated" and draws in areas that it should not. This command resets the entire window to the proper size.

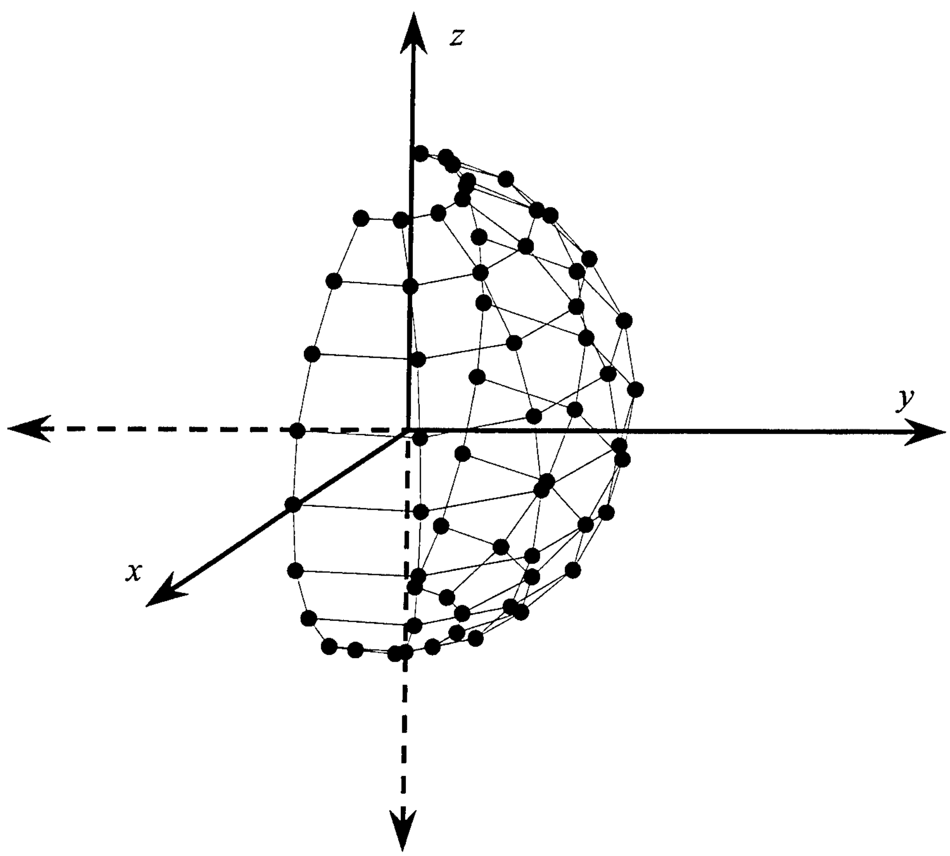

Figure 10. Half-Sphere Array

QUARTER-SPHERE ARRAY

This routine creates a quarter-sphere array (typically a submarine bow array), as shown in figure 11. Broadside to this array is an azimuthal steer angle of 0° and a polar steer angle of 90°. The following commands are available:

Number of Columns – Changes the number of columns in the array. Columns are equally spaced in the azimuthal angular direction, starting at $x = r$ and $y = 0$ and ending at $x = -r$ and $y = 0$.

Array Radius (m) – Changes the radius of the array (units are entered in meters).

Column Shading – Sets the aperture shading along the length of the columns. Shading is available using uniform (boxcar), hamming, hanning, or triangular weights.

Number of Rows – Changes the number of rows in the array. The rows are equally spaced in the polar angular direction, starting at $z = 0$ and incrementing to 180° minus the spacing angle (not 180°).

Row Shading – Sets the aperture shading along the length of the row. Shading is available using uniform (boxcar), hamming, hanning, or triangular weights. If hamming, hanning, or triangular shading is selected, the maximum weight value corresponds to the row located at $y = r$ (the front of the submarine).

Input Integration Parameters – Directs the program to the next window, which inputs the integration parameters.

Return to Start – Directs the program back to the initial window without running an analysis.

Exit Program – Exits the GenDI program and closes associated windows.

Reset Graphics – Resets the graphics window. The MATLAB graphics window sometimes becomes "contaminated" and draws in areas that it should not. This command resets the entire window to the proper size.

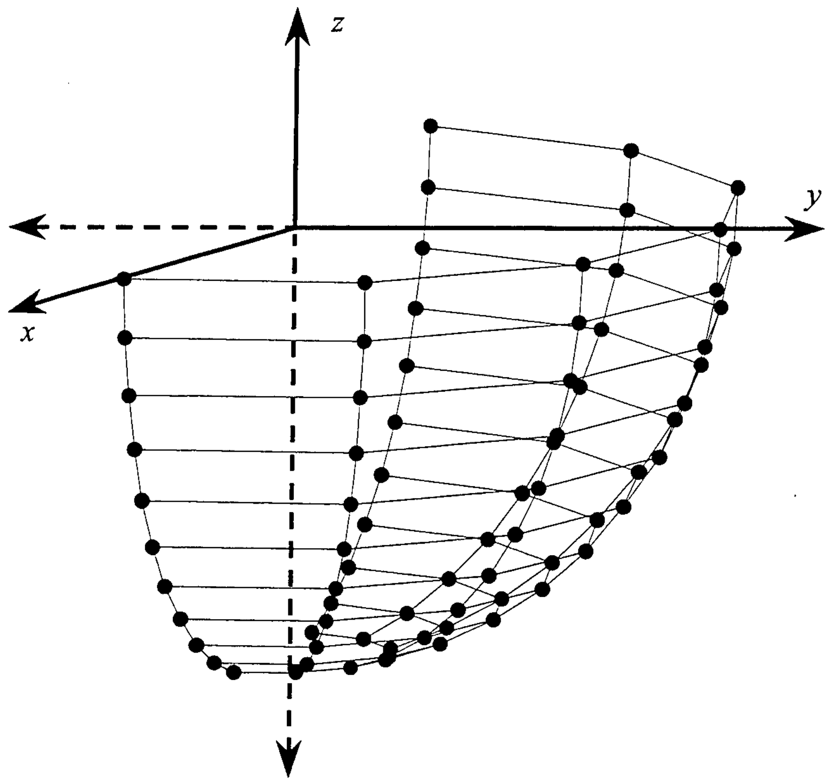

Figure 11. Quarter-Sphere Array

READING ARRAY COORDINATES FROM A USER-GENERATED FILE

If the array geometry is not one of the 10 predefined shapes or 4 predefined weights, then it can be read in as either an ASCII file or a MATLAB binary file. The MATLAB binary file that the program reads is the GenDI output file. The ASCII file that the program reads is a comma-delimited file that contains (1) x, y, and z or (2) x, y, and z, along with the shade value of each sensor on each subsequent line. If no shade values are included in the file, then a value of unity (1) is assigned to each sensor. The filename must contain an .asc suffix for the program to recognize this file type. The following commands are available in the read file window:

Read New File – Reads the array geometry file into GenDI.

Channel Number – Sets the specific channel number and corresponding x, y, and z, along with the shade values, into the next four display boxes. This command is for online editing purposes.

X Value (m) – Indicates the x-value of the displayed channel number in meters (can be edited).

Y Value (m) – Indicates the y-value of the displayed channel number in meters (can be edited).

Z Value (m) – Indicates the z-value of the displayed channel number in meters (can be edited).

Shade Value – Indicates the shade value of the displayed channel number (can be edited).

Input Integration Parameters – Directs the program to the next window, which inputs the integration parameters.

Return to Start – Directs the program back to the initial window without running an analysis.

Exit Program – Exits the GenDI program and closes associated windows.

Turn Channel Number On – Turns the channel numbers on or off on the plot of the array geometry (via a toggle switch).

Reset Graphics – Resets the graphics window. The MATLAB graphics window sometimes becomes "contaminated" and draws in areas that it should not. This command resets the entire window to the proper size.

CHANGING VIEWING ATTRIBUTES OF THE PROGRAM

Additionally, there are seven commands available in the preprocessing phase that change the viewing attributes of the program:

Black Background on Plots With Black Border – Changes the plot background to black and the text background to black.

White Background on Plots With Grey Border – Changes the plot background to white and the text background to gray.

Black Background on Plots With Grey Border – Changes the plot background to black and the text background to gray.

Average Text Size 8 pt – Changes the average text size of the display to 8 points (does not affect the program in any other manner).

Average Text Size 10 pt – Changes the average text size of the display to 10 points (does not affect the program in any other manner).

Average Text Size 12 pt – Changes the average text size of the display to 12 points (does not affect the program in any other manner).

Average Text Size 14 pt – Changes the average text size of the display to 14 points (does not affect the program in any other manner).

ADDITIONAL PROGRAM COMMANDS

Finally, there are two commands that direct the program at the preprocessing level:

Post Process Existing Data – Sends the program to the postprocessing module.

Quit GenDI Program – Quits the program, clears the memory, and closes all associated windows. This command does not terminate the MATLAB session.

3. DIRECTIVITY INDEX COMPUTATION

After the array geometry and weights have been entered, the next step is to compute the directivity index. The several parameters available during this step are described below:

Number of Azimuthal Steer Angles - Changes the number of azimuthal steer angles. Either the number of azimuthal steer angles <u>or</u> the number of polar steer angles must be set to 1.

Azimuthal Steer Angles (degrees) - Changes the azimuthal steer angles (units are entered in degrees). The default values are all 0°.

Number of Polar Steer Angles - Changes the number of polar steer angles. Either the number of polar steer angles <u>or</u> the number of azimuthal steer angles must be set to 1.

Polar Steer Angles (degrees) - Changes the polar steer angles (units are entered in degrees). The default values are all 90°.

Number of Frequencies - Changes the total number of frequencies in the analysis. If the frequency spacing is one-third octave, this number is set by the program rather than by the user.

Low Frequency (Hz) – Sets the low-frequency value of the analysis in Hertz. If the frequency spacing is one-third octave, this number is rounded down to the nearest one-third octave frequency.

High Frequency (Hz) – Sets the high-frequency value of the analysis in Hertz. If the frequency spacing is one-third octave, this number is rounded up to the nearest one-third octave frequency.

Frequency Spacing – Sets the frequency spacing to either one-third octave, log, or linear spacing.

Wave Speed – Sets the wavespeed of the analysis in meters per second. A typical value is 1500 m/s.

Baffle Condition – Provides an increase in the directivity index to correspond to a fully baffled array. This command is executed by adding 3.01 dB to the unbaffled array results.

Element Shading – Allows for different types of element shading to be applied to an array. Common element shadings included are cos θ, cos ϕ, and cos θ cos ϕ.

Integration Points Azimuthal Direction – Sets the number of integration points in the azimuthal direction. The default value is 10 times the number of sensors.

Integration Points Polar Direction – Sets the number of integration points in the polar direction. The default value is 5 times the number of sensors.

Calculate Directivity Index – Routes the program on to calculating the directivity index of the array. Before the directivity index is calculated, the user is prompted for a filename to store the data. Neither the filename nor the directory to which it is written should contain any blank characters. The default filename is "DI" plus the run number assigned to the analysis. The run number is incremented by one every time an analysis is computed. Directivity index results are stored in a MATLAB binary file.

Return to Start – Returns the program to the initial window without running an analysis.

Exit – Exits the program.

4. POSTPROCESSING

After the directivity index has been calculated, the next step is to postprocess the results, which is done by graphical display, numerical display, or a written numeric ASCII file, as described below. After the program runs the computation, the plotting routine is displayed with the previous computation set as the default value in the first data set memory. The postprocessing parameters are described below in the approximate order in which they are displayed:

GRAPHICAL DISPLAY

Minimum Frequency (Hz) – Shows the minimum display frequency of the plot in Hertz.

Maximum Frequency (Hz) – Shows the maximum display frequency of the plot in Hertz.

Minimum Response (dB) – Shows the minimum display response of the plot in decibels.

Maximum Response (dB) – Shows the maximum display response of the plot in decibels.

Frequency Axis Scaling – Sets the frequency-axis scaling of the plot to log or to linear.

Figure Tag (Data Set One Only) – Turns the figure tag on or off for the first data set. If this tag is on, then the parameters used to calculate the directivity index of data set one are displayed at the bottom of the plot.

Marker Size – Sets the size of the markers on the plots if discrete markers are used (see Data Marker command).

Figure Grid – Turns the figure grid on the plot on or off.

Figure Legend– Turns the figure legend on the plot on or off. The figure legend consists of the filename and the steer angle if they are available.

The graphical program has the capability to plot four different data sets simultaneously using the following commands (with the next four commands identical for each data set):

Change – Loads a new data set into memory, which is accomplished by reading a previously generated data set file or an ASCII file.

Plot Color – Changes the color of the data set when it is plotted.

Data Marker – Changes the type of marker associated with the particular data set.

Clear – Clears the data set from memory.

Large Size Plot – Causes the displayed plot to cover most of the screen. This command is toggled with small size plot.

Small Size Plot – Causes the displayed plot to cover about half the screen. This command is toggled with large size plot.

Go to Program Start – Returns the program to the initial screen.

Quit GenDI Program – Quits the program, clears the memory, and closes all associated windows. This command does not terminate the MATLAB session.

NUMERICAL DISPLAY/NUMERIC ASCII FILE

Numeric Post Processing – Directs the program to the numeric postprocessing module. This module contains the following five commands:

Load File – Loads a previously generated GenDI analysis file into memory and displays the results in table form on the computer screen. If more than one steering angle was specified in the analysis, a magenta-colored button is used to page through the data set. When there are additional data, the text will read "Next Data Set" and the data can be accessed by depressing the button. If there are no additional data, the text will read "End of Data Set."

Write Array Parameters to ASCII File (Along with Data) – Allows the user to write the array parameters to an ASCII file along with the data. The default value is on.

Write ASCII File – Writes the data to a user-specified ASCII file. The user is prompted to enter a filename upon which the program appends a ".txt" suffix to identify the filetype.

Go to Program Start – Returns the program to the initial screen.

Quit GenDI Program – Quits the program, clears the memory, and closes all associated windows. This command does not terminate the MATLAB session.

5. PROGRAM VALIDATION

The program is now validated using three simple geometrical array shapes that provide either a closed-form solution or an approximation of the directivity index. These arrays do not correspond to any actual naval systems but are chosen only for comparison purposes.

HORIZONTAL LINE ARRAY

The first array is an equally spaced horizontal line array with 16 sensors and a sensor-to-sensor spacing of 2 m. The wavespeed used in this computation was 1500 m/s and the steer angles were 45° in the azimuthal direction and 90° in the polar direction. The closed-form solution of the directivity factor for this problem is given by Nielsen[6] as

$$DF = \frac{M}{1 + \frac{2}{M} \sum_{m=1}^{M-1} (M-m) \left\{ \cos\left[r \sin(\theta_s)\right] \right\} \left[\frac{\sin(r)}{r} \right]}, \tag{10}$$

with

$$r = \frac{\omega m d}{c}, \tag{11}$$

where M is the total number of sensors and d is the sensor-to-sensor separation distance. The directivity index is computed from equation (1).

Figure 12 compares the directivity index of the exact solution to the GenDI solution using 160 integration points in the azimuthal direction and 80 points in the polar direction at each frequency. The number of integration points corresponds to the program default of 10 times the number of sensors in the azimuthal direction and 5 times the number of sensors in the polar direction. The difference between the directivity factor of the exact solution and the numeric (GenDI) solution is 0.24 percent.

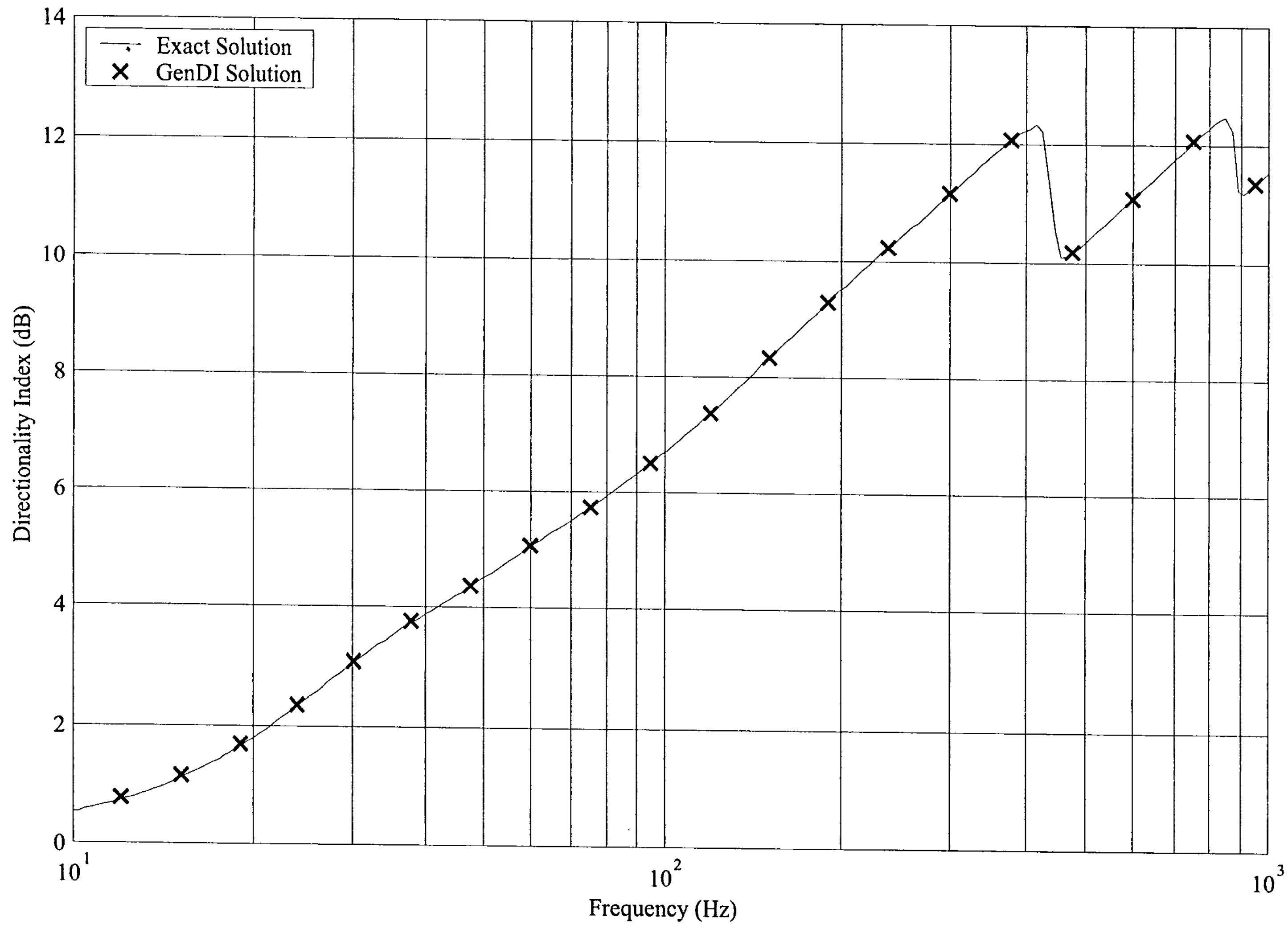

Figure 12. Comparison of Exact Solution and Generic Directivity Index Program Solution for a Line Array

PLANAR ARRAY

The second geometrical shape is a planar array that consists of four rows by six columns. Sensor-to-sensor spacing is 0.5 m and the wavespeed used for the computations is 1500 m/s. An approximation of the directivity factor for a baffled planar array is given by Molloy[4] as

$$DF = \frac{L_x L_y \omega^2}{\pi c^2} , \tag{12}$$

where L_x and L_y are the effective acoustic lengths of the aperture in the x- and y-directions, respectively. The acoustic length includes the physical array size plus half the amount of the sensor-to-sensor spacing that is added to each end of the array. The directivity index is computed with equation (1).

The approximation given in equation (12) is only valid in the unaliased frequency range of the array, a value determined by

$$f_u \le \frac{c}{2d} , \tag{13}$$

where f_u is the unaliased frequency in Hertz and d is the maximum sensor-to-sensor spacing of the array (m). For this array, the unaliased frequency range ends at 1500 Hz.

Figure 13 compares the directivity index of the approximate solution to the GenDI solution using 240 integration points in the azimuthal direction and 120 points in the polar direction at each frequency with the baffle condition turned on. The number of integration points corresponds to the program default of 10 times the number of sensors in the azimuthal direction and 5 times the number of sensors in the polar direction. The difference between the directivity index of the approximate solution and the numeric (GenDI) solution is not calculated because the closed-form solution is only an approximation and because the solution space has been extended beyond the aliasing frequency of the array to illustrate the divergence of the two solution methods.

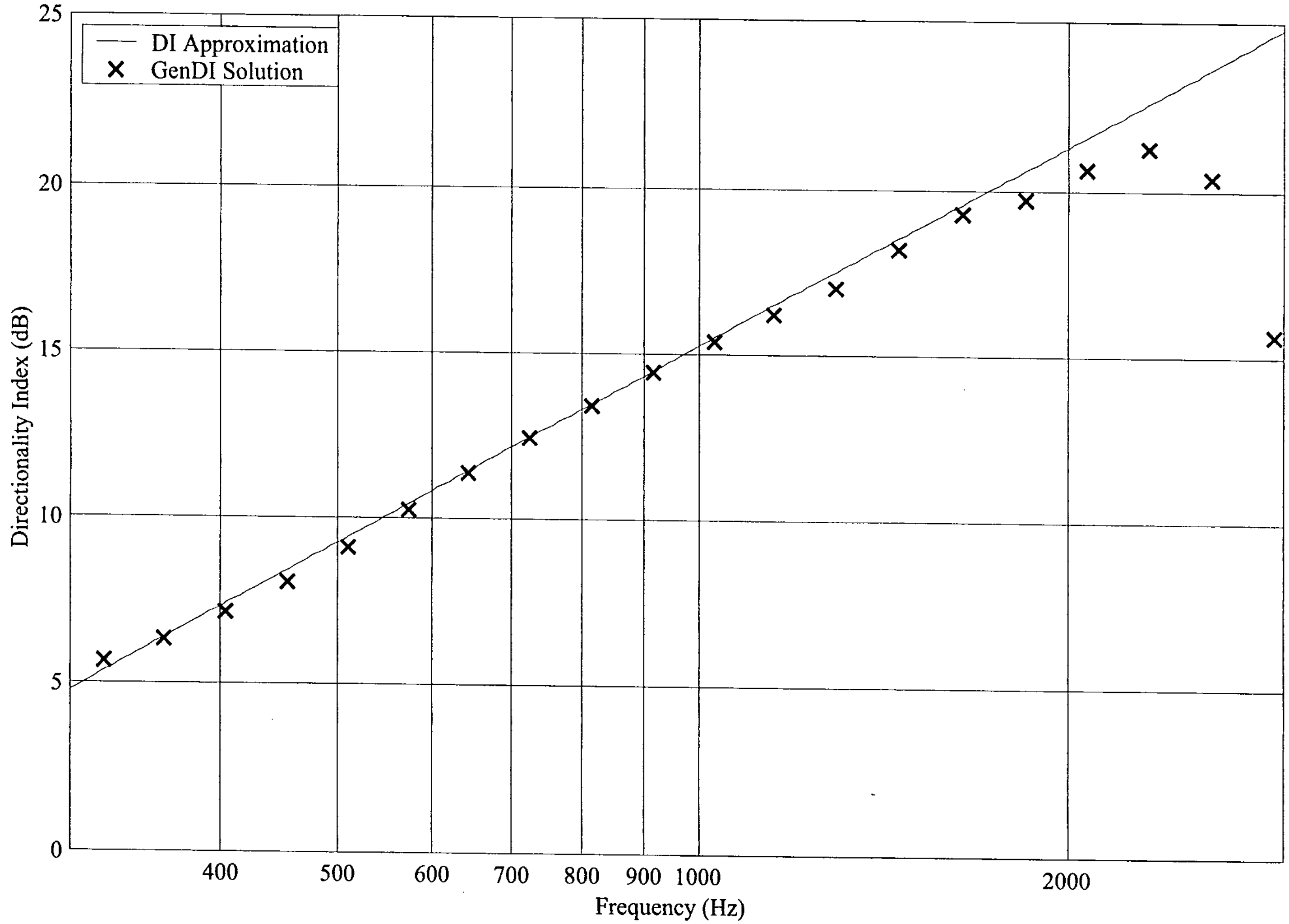

Figure 13. Comparison of Approximate Solution and Generic Directivity Index Program Solution for a Planar Array

VOLUMETRIC ARRAY

The third geometrical shape is a volumetric array that consists of four rows of sensors in the x-direction, eight columns of sensors in the y-direction, and three sensors (high) in the z-direction. The sensor-to-sensor spacing is 0.5 m and the wavespeed used for the computations is 1500 m/s. An approximation of the directivity factor for a volumetric array is shown in Nuttall and Cray[1] as

$$DF = \frac{\omega^2}{3c^2}\left[L_x^2 L_y^2 \cos^2(\phi_s) + L_x^2 L_z^2 \sin^2(\theta_s)\sin^2(\phi_s) + L_y^2 L_z^2 \cos^2(\theta_s)\sin^2(\phi_s)\right]^{1/2}, \tag{14}$$

where L_x, L_y, and L_z are the effective acoustic lengths of the aperture in the x-, y-, and z-directions, respectively. The acoustic length includes the physical array size plus half the amount of the sensor-to-sensor spacing that is added to each end of the array. The directivity index is computed using equation (1).

The approximation given in equation (14) is only valid in the unaliased frequency range of the array, a value determined by equation (13). For this array, the unaliased frequency range ends at 1500 Hz.

Figure 14 compares the directivity index of the approximate solution to the GenDI solution using 960 integration points in the azimuthal direction and 480 points in the polar direction at each frequency with the baffle condition turned off. The number of integration points corresponds to the program default of 10 times the number of sensors in the azimuthal direction and 5 times the number of sensors in the polar direction. The difference between the directivity index of the approximate solution and the numeric (GenDI) solution is not calculated because the closed-form solution is only an approximation and because the solution space has been extended beyond the aliasing frequency of the array to illustrate the divergence of the two solution methods.

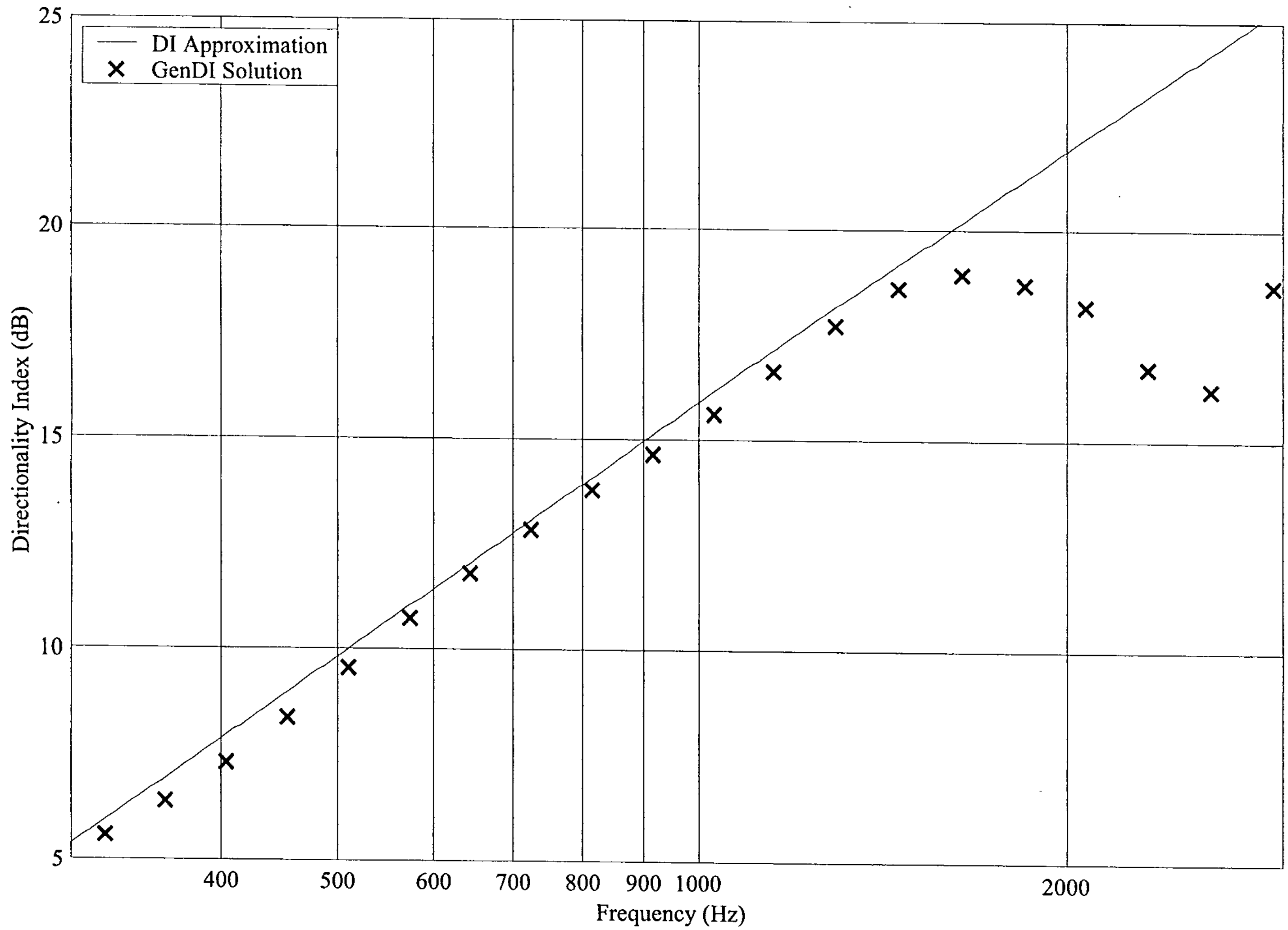

Figure 14. Comparison of Approximate Solution and Generic Directivity Index Program Solution for a Volumetric Array

6. PROGRAM FLOWCHARTS

The program subroutines are presented in figure 15, which shows the preprocessing subroutines, and in figure 16, which shows the analysis and postprocessing routines.

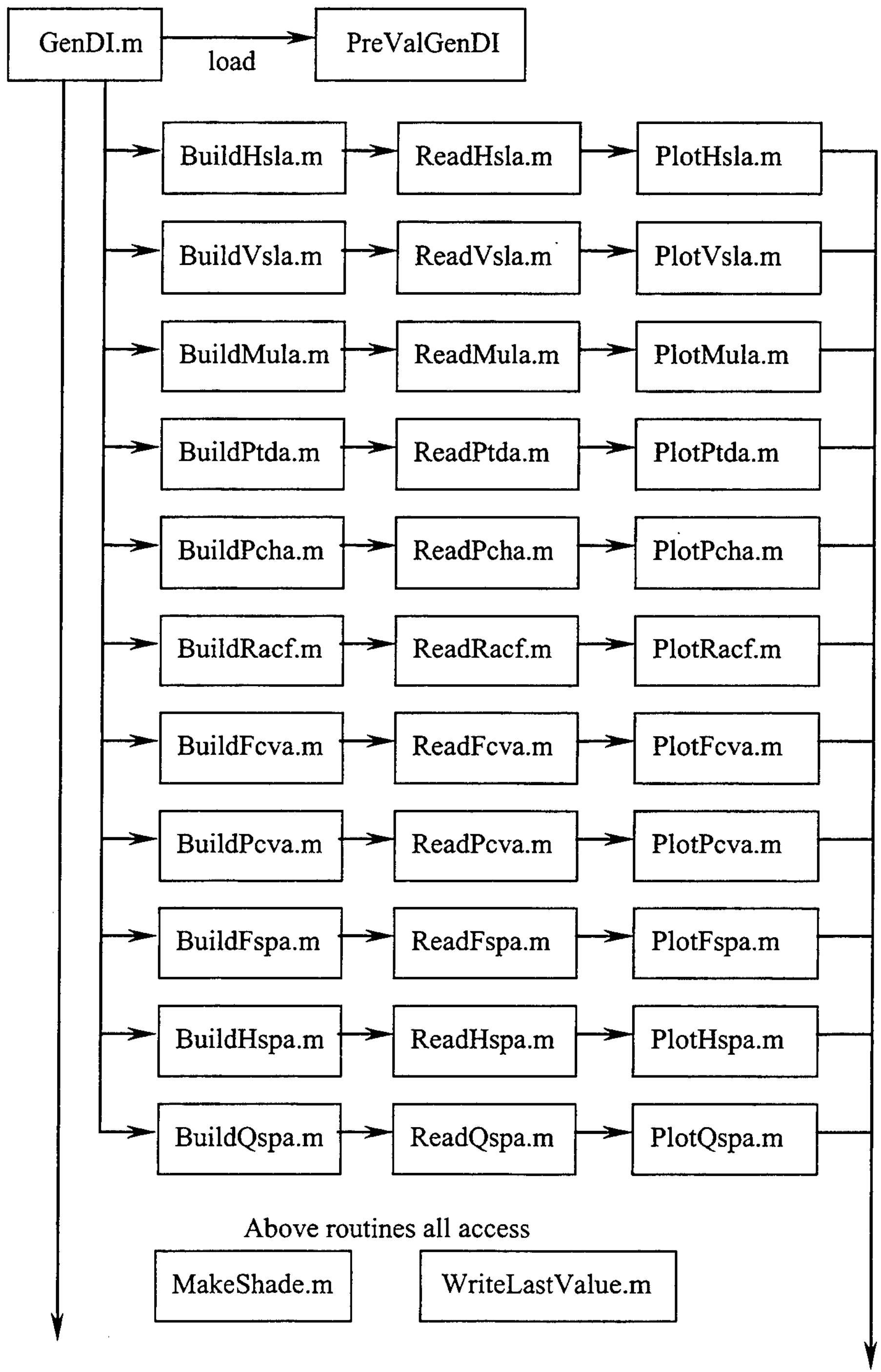

Figure 15. Flowchart of Preprocessing Subroutines

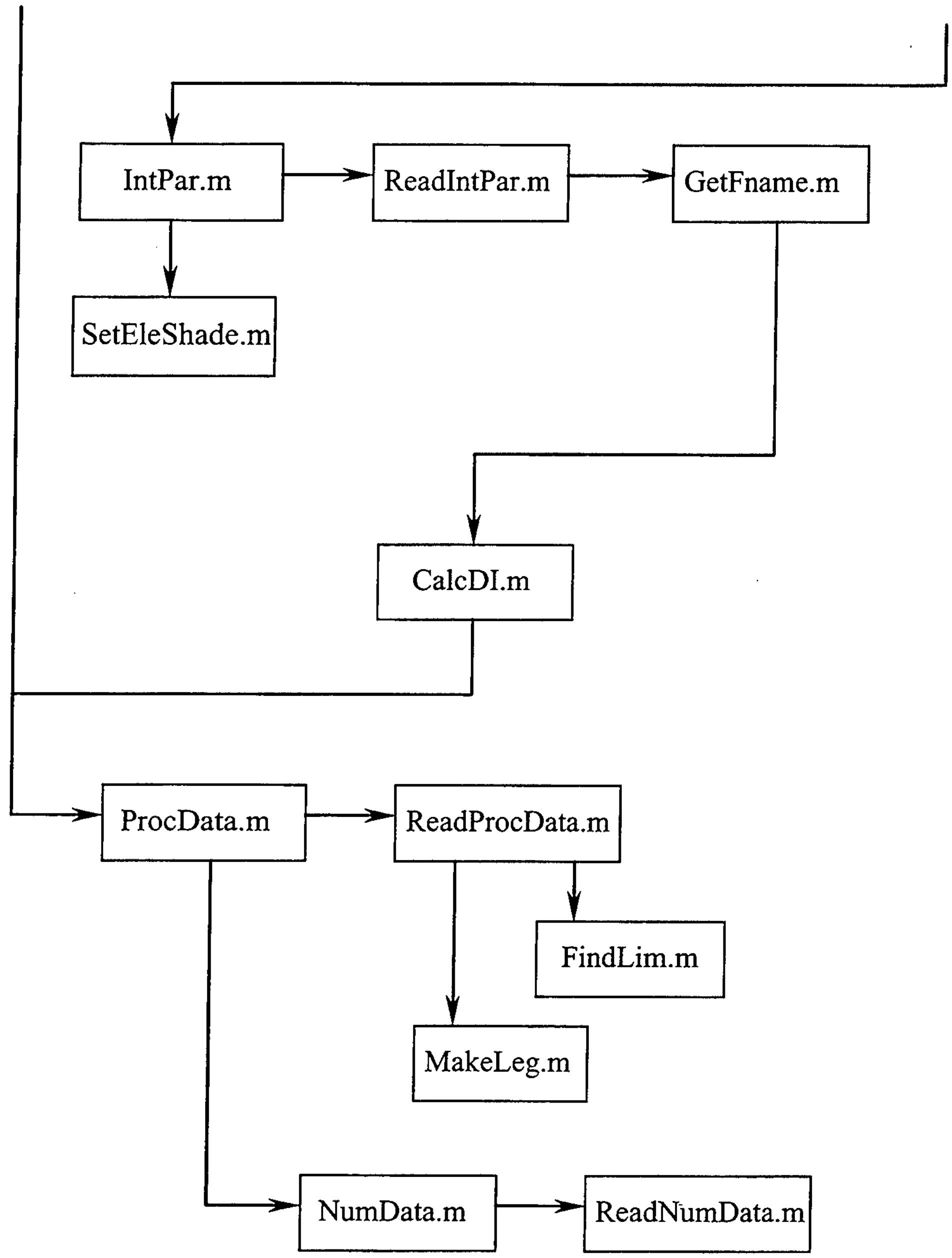

Figure 16. Flowchart of Analysis and Postprocessing Subroutines

REFERENCES

1. Albert H. Nuttall and Benjamin A. Cray, "Approximation to Directivity for Linear, Planar, and Volumetric Apertures and Arrays," NUWC-NPT Technical Report 10,798, Naval Undersea Warfare Center Division, Newport, RI, 25 July 1997.

2. V. C. Anderson and J. C. Munson, "Directivity of Spherical Receiving Arrays," *Journal of the Acoustical Society of America*, vol. 35, no. 8, 1963, pp. 1162-1168.

3. R. J. Bobber, "Approximations to the Directivity Index," NRL Report 7750, Naval Research Laboratory, Washington, DC, May 1974.

4. C. T. Molloy, "Calculation of the Directivity Index for Various Types of Radiators," *Journal of the Acoustical Society of America*, vol. 20, 1948, pp. 387-405.

5. Albert H. Nuttall and Benjamin A. Cray, "Efficient Calculation of Directivity Indices for Certain Three-Dimensional Arrays," NUWC-NPT Technical Report 11,129, Naval Undersea Warfare Center Division, Newport, RI, 26 July 1996.

6. R. O. Nielsen, *Sonar Signal Processing*, Artech House, Norwood, MA, 1991.

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